Correlation Analysis Between Rumen Degradation Characteristics of Common Concentrate Feeds for Meat Sheep and In Vitro Small Intestinal Digestibility of Rumen Undegraded Protein (Postprint)

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Abstract

This study investigated the correlation between rumen degradation characteristics of 10 commonly used concentrate feeds for meat sheep and the in vitro small intestinal digestibility of Rumen Undegradable Protein (RUDP), aiming to provide a basis for estimating Metabolizable Protein (MP) in meat sheep. Six 14-month-old Dorper × Han crossbred meat sheep wethers with permanent rumen fistulas, averaging
(49.27$±3.12)*kgbodyweight*, *wereusedtodeterminetherumendegradabilityofDryMatter*(*DM*), *OrganicMatte*
stepinvitromethod, *andtoconductcorrelationanalysisbetweenRUDPinvitrosmallintestinaldigestibilityandnu*
0.01).*TheRUDPinvitrosmallintestinaldigestibilityofsorghum*, *corn*, *barley*, *wheat*, *oats*, *rapeseedmeal*, *pean*
In conclusion, based on the strong correlation between RUDP in vitro small intestinal digestibility and nutrient contents and rumen effective degradability of nutrients in 10 commonly used concentrate feeds for meat sheep, the RUDP in vitro small intestinal digestibility can be effectively estimated through nutrient contents or effective degradability of feed ingredients.

Full Text

Correlation Analysis of Ruminal Degradation Characteristics and in Vitro Small Intestinal Digestibility of Rumen Undegraded Protein of Common Concentrates for Mutton Sheep

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Abstract

This study investigated the correlation between ruminal degradation characteristics and in vitro small intestinal digestibility of rumen undegraded protein (RUDP) in ten common concentrates for mutton sheep, aiming to provide a basis for estimating metabolizable protein (MP) in mutton sheep. Six 14-month-old Dorper × thin-tailed Han crossbred wethers with an average body weight of
(49.27$±3.12)*kg*, *fittedwithpermanentruminalfistulas*, *wereused*.*Thenylonbagtechniqueandanimprovedthre*
stepinvitroprocedurewereemployedtodeterminetheruminaldegradationratesofdrymatter(*DM*), *organicmatt*
0.01).*TheinvitrosmallintestinaldigestibilityofRUDPforsorghum*, *corn*, *barley*, *wheat*, *oat*, *rapeseedmeal*, *pe*
0.896).*TheregressionequationbetweenRUDPsmallintestinaldigestibility*(*Y*)*andeffectivedegradabilityofD*
Y = 1.08 + 0.17*X*{1}+0.91*X*{2}−1.57*X*{3}$ (R^2=0.814). In conclusion, based on the strong correlations between the in vitro small intestinal digestibility of RUDP and both nutrient contents and ruminal effective degradability in these ten common concentrates for mutton sheep, it is feasible to estimate the in vitro small intestinal digestibility of RUDP using either nutrient contents or nutrient effective degradability.

Keywords: mutton sheep; concentrate; ruminal degradability; in vitro small intestinal digestibility of rumen undegraded protein; metabolizable protein

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Introduction

Concentrates are the primary source of protein in ruminant diets. Accurate determination of protein utilization in ruminants can reduce feed waste and lower costs. For ruminants, the rumen-degraded protein (RDP) and rumen-undegraded protein (RUDP) system is currently used to evaluate protein utilization. The core of this system involves measuring ruminal protein degradability and estimating the in vitro small intestinal digestibility of RUDP. The nylon bag technique is commonly used to determine ruminal protein degradability [?]. Researchers such as Zhao Liansheng et al. [?] and Chen Yan [?] have investigated the ruminal degradability of single feed ingredients in beef cattle or dairy cows using this method. However, methods for determining the in vitro small intestinal digestibility of RUDP vary, including fistula methods, mobile nylon bag techniques, and in vitro methods. Fistula and mobile nylon bag methods require surgical installation of fistulas, which is costly, and the physical condition of experimental animals significantly affects results, with low postoperative survival rates. Additionally, the narrow digestive tract of sheep makes the mobile nylon bag technique prone to causing intestinal blockage. The three-step in vitro method proposed by Gargallo et al. [?] overcomes these disadvantages. Wang Yan et al. [?] used four different methods—mobile nylon bag, improved three-step in vitro, original three-step in vitro, and acid detergent insoluble nitrogen—to determine the in vitro small intestinal digestibility of RUDP in 13 feedstuffs, concluding that the improved three-step in vitro method showed good correlation with the mobile nylon bag method (R^2=0.8383). Zhu Yajun et al. [?] used the three-step in vitro method to determine the in vitro small intestinal digestibility of RUDP in major concentrates for sheep in Shandong Province. The ruminal degradability and in vitro small intestinal digestibility of RUDP in common concentrates for mutton sheep serve as the basis for estimating intestinal metabolizable protein (MP), yet few reports exist on this topic. This study employed the nylon bag technique and improved three-step in vitro method to investigate the correlations between the in vitro small intestinal digestibility of RUDP and nutrient contents and ruminal effective degradability in ten common concentrates for mutton sheep, providing a reference for establishing an MP estimation system for mutton sheep in China.

Materials and Methods

1.1 Sample Collection and Preparation The experimental samples consisted of ten common concentrates for mutton sheep: sorghum, corn, barley, wheat, oat, rapeseed meal, soybean meal, cottonseed meal, peanut meal, and corn distiller' s dried grains with solubles (cDDGS). Meal-type feeds were processed using the extraction method, while cereal grains were ground directly to approximately 5.0 mm particle size using a grinder. The cDDGS, having inherently small particles, was used directly after purchase. All ten concentrates were ground through a 2.5 mm sieve for subsequent analysis.

1.2 Experimental Animals and Management The experiment utilized six healthy 14-month-old Dorper ( ) × thin-tailed Han ( ) crossbred wethers with an average body weight of (49.27$±$3.12) kg, fitted with permanent ruminal fistulas. Animals were fed twice daily at 06:00 and 18:00, receiving 600 g per feeding, with free access to water. The composition and nutrient levels of the basal diet are presented in Table 1 .

Table 1 Composition and nutrient levels of the basal diet (DM basis)

Items	Content
Ingredients	
Chinese wildrye	
Corn	
Soybean meal	
$CaHPO_4$	
NaCl	

Items	Content
Premix1)	
Total	
Nutrient levels2)	
DM	
OM	
CP	
NDF	
ADF	

1) The premix provides the following per kg of diet: VA 15,000 IU, VD 5,000 IU, VE 50 mg, Fe 90 mg, Cu 12.5 mg, Mn 60 mg, Zn 90 mg, Se 0.3 mg, I 1.0 mg, Co 0.3 mg.
2) Nutrient levels are measured values.

1.3 Nylon Bag Preparation Nylon cloth with a pore size of 50 m was used to prepare 10 cm × 6 cm bags, sewn with double-stitched polyester thread. The bottom corners were rounded to prevent sample residue, and edges were singed with an alcohol lamp to prevent fraying. Bags were labeled with oil-based markers and preconditioned by incubating in the rumen for 72 h, then removed, washed, and dried before use. A 25 cm semi-flexible plastic tube was prepared with a 3 cm slit 1-2 cm from one end to secure the nylon bag, and a 0.3 cm diameter hole 1-2 cm from the other end for attaching nylon string.

1.4.1 Ruminal Degradability of Dry Matter (DM), Organic Matter (OM), and Crude Protein (CP) Each sample was tested in triplicate, with each replicate using a different sheep. Samples were incubated for five time points: 6, 12, 24, 36, and 48 h, with two parallel bags per time point. Approximately 6 g of sample was weighed into pre-weighed nylon bags, with two parallel bags attached to one plastic tube. Bags were inserted into the rumen 2 h after feeding, with different time points inserted separately but removed simultaneously. Upon removal, bags were immediately immersed in cold water with the plastic tube. Bags were hand-washed with multiple water changes until the filtrate was clear, taking care not to squeeze or rub the bags (0 h bags were also washed). Washed bags (with residues) were dried in a vacuum or forced-air oven at 65 °C for 48 h, equilibrated for 24 h, and weighed. Residues from the two parallel bags were combined in one ziplock bag for DM, OM, and CP analysis.

1.4.2 Determination of in Vitro Small Intestinal Digestibility of RUDP Following Hvelplund’ s method [**?**], 5 g of sample was weighed into nylon bags and incubated in the rumen for 16 h, then removed, washed until clear, dried at 55 °C for 48 h, and ground to pass a 40-mesh sieve. Following Gargallo et al. [**?**], 0.5 g of rumen-incubated residue was placed in Ankom

F57 filter bags, sealed, and 30 bags from the same sheep were placed in one incubation jar with 2 L of pre-incubated pepsin-HCl solution [1 g pepsin (P-7000, Sigma, USA) per liter, pH adjusted to 1.9 with 0.1 N HCl]. Jars were incubated at 39 °C for 1 h in a Daisy II incubator (Ankom, USA) with agitation. After incubation, bags were rinsed with tap water until clear, then transferred to jars containing pre-warmed pancreatin solution [50 mg thymol and 3 g pancreatin (P-7545, Sigma, USA) per liter, pH adjusted to 7.75 with potassium phosphate buffer] and incubated at 39 °C with agitation for 24 h. Bags were then rinsed with tap water until clear, dried at 55 °C to constant weight, weighed, and analyzed for nutrient content.

1.5 Measurement Indicators and Methods DM, OM, and CP contents were determined according to Zhang Liying [?]. For neutral detergent fiber (NDF) and acid detergent fiber (ADF) determination, samples were first enzymatically digested with trypsin and amylase before following the Van Soest detergent fiber analysis procedure.

1.6.1 Ruminal Degradability Ruminal degradability of concentrate samples at different time points was calculated as:

$$A = 100 \times (B - C)/B$$

where:
- A = ruminal degradability of the nutrient (%)
- B = mass of the nutrient in the original sample (g)
- C = mass of the nutrient in the residue (g)

1.6.2 Ruminal Effective Degradability Following Ørekov et al. [?], parameters a, b, and c in the model were calculated using the least squares method:

$$dP = a + b(1 - e^{-ct})$$

where:
- dP = ruminal degradability of a nutrient at time t (%)
- a = rapidly degradable fraction (%)
- b = slowly degradable fraction (%)
- c = degradation rate of slowly degradable fraction (%/h)
- t = ruminal incubation time (h)

Values of a, b, and c were calculated using the SAS 9.1 NLIN procedure. Effective degradability (D) was calculated as:

$$D = a + bc/(c + k)$$

where:

- D = effective degradability of a nutrient (%)
- k = passage rate of the concentrate (%/h), taken as 0.08%/h according to Feng Yanglian et al. [?]

1.6.3 in Vitro Small Intestinal Digestibility of RUDP Calculations were performed as follows:

$$\text{RUDP content (\%)} = \text{CP content of concentrate (\%)} \times [1 - \text{ruminal CP degradability (\%)}]$$

$$\text{in vitro small intestinal digestibility of RUDP (\%)} = 100 \times [\text{RUDP content (\%)} - \text{CP content in residue (\%)}]/\text{R}$$

1.7 Statistical Analysis Data were analyzed using the ANOVA procedure, with $P<0.05$ considered statistically significant. Results are expressed as means and standard error of the mean (SEM).

Results

Nutrient Contents of Ten Concentrates As shown in Table 2 , DM content ranged from 89.59% to 92.28%, showing little variation. OM content varied considerably, with corn having the highest at 98.79% and soybean meal the lowest at 92.50%. Peanut meal had the highest CP content, followed by soybean meal, cottonseed meal, rapeseed meal, cDDGS, oat, wheat, sorghum, and barley; corn had the lowest CP content at only 8.88%. NDF and ADF contents differed markedly among concentrates, with cDDGS having the highest NDF content (23.97%) and oat the lowest (10.25%). Cottonseed meal had the highest ADF content (14.60%), while sorghum had the lowest (3.01%).

Table 2 Nutrient contents of ten kinds of concentrates (DM basis)

Items	Sorghum	Barley	Wheat	Rapeseed meal	Peanut meal	Cottonseed meal	Soybean meal	cDDGS
DM								
OM								
CP								
NDF								
ADF								

Ruminal Degradation Characteristics of Ten Concentrates As shown in Table 3 , DM degradability increased progressively with longer ruminal incubation time, with significant differences observed among concentrates at the same time point. The degradation rate increased more slowly during 6–24 h than during 24–48 h. Oat exhibited significantly higher DM degradability than the other nine concentrates at all time points (P<0.05). Oat had the highest DM effective degradability at 57.38%, followed by soybean meal, cDDGS, peanut meal, cottonseed meal, wheat, sorghum, barley, rapeseed meal, and corn, which had the lowest ruminal degradability at 41.52%.

Table 3 DM ruminal degradability and degradation parameters of ten kinds of concentrates

Items	Sorghum	Barley	Wheat	Rapeseed meal	Peanut meal	Cottonseed meal	Soybean meal	cDDGS	P-value
Ruminal degradability of DM									
6 h	17.48cd	26.23c	22.63cd	40.61b	47.37a	20.46cd	18.16cd	16.08d	23.48cd
12 h	23.65d	31.38c	31.48c	50.90b	63.40a	32.01c	22.41d	20.79d	32.79c
24 h	35.33bc	35.13bc	39.30bc	59.01a	69.69a	37.98bc	34.27bc	31.97c	41.95b
36 h	42.83de	38.46e	59.63bc	68.70b	77.83a	43.27de	41.66de	38.25e	51.84cd
48 h	56.45cd	50.65de	69.55bc	79.47ab	82.42a	56.34cde	51.11de	49.62e	62.43cd
Ruminal degradation parameters of DM									
a (%)	18.53e	26.64bc	19.37de	26.95bc	49.46a	23.07bcd	20.17cde	19.57de	25.80bc
b (%)	59.25ab	27.80c	73.70a	56.08ab	38.09c	51.64b	64.69ab	64.56ab	62.12ab
c (%/h)	0.04b	0.06a	0.03bc	0.04b	0.02c	0.04bc	0.04b	0.04b	0.03bc
ED (%)	46.43bc	41.52cd	44.79cd	48.53bc	57.38a	44.63cd	49.21bc	48.76bc	53.83ab

Note: a = rapidly degraded fraction, b = slowly degraded fraction, c = degrada-

tion rate of slowly degraded fraction, ED = effective degradability. In the same row, values with different superscripts differ significantly (P<0.05). The same applies below.

As shown in Table 4 , OM degradability varied considerably among the ten concentrates at the same time point. Oat exhibited significantly higher OM degradability than the other nine concentrates at all time points (P<0.05) (except at 48 h compared with wheat). At 24 h, wheat had an OM degradability of 59.62%, second only to oat at 73.71%, and significantly higher than the other eight concentrates (P<0.05). Oat had significantly higher OM effective degradability than other concentrates (P<0.05). Among cereal grains, oat had the highest OM effective degradability, while among meals, soybean meal had the highest.

Table 4 OM ruminal degradability and degradation parameters of ten kinds of concentrates

Items	Sorghum	Barley	Wheat	Rapeseed meal	Peanut meal	Cottonseed meal	Soybean meal	cDDGS	P-value
Ruminal degradability of OM									
6 h	23.08de	28.78c	25.03cd	42.68b	53.68a	22.21de	18.40e	17.02e	19.85de
12 h	27.91cde	34.57cd	37.43c	49.85b	68.69a	30.17cde	27.68cde	21.52e	25.77de
24 h	41.82c	39.57c	43.53c	59.62b	73.71a	39.27c	38.54c	35.04c	40.19c
36 h	44.81cd	44.11cd	53.74bc	63.94b	79.45a	45.92cd	44.13cd	40.14d	49.46cd
48 h	57.37cd	51.47cd	63.77bc	76.74ab	86.84a	58.73cd	55.65cd	49.84d	62.86cd
Ruminal degradation parameters of OM									
a (%)	21.74def	26.07cd	22.05de	33.48b	51.40a	25.22cde	20.62ef	19.45f	22.25def

Items	Sorghum	Barley	Wheat	Rapeseed meal	Peanut meal	Cottonseed meal	Soybean meal	cDDGS	P-value
b (%)	64.03a	45.80abc	57.35bc	46.30bc	30.98d	64.15a	53.81abc	66.33a	60.94ab
c (%/h)	0.03de	0.03cd	0.03cd	0.03de	0.01f	0.02e	0.05a	0.04bc	0.05ab
ED (%)	44.55b	44.09b	44.39b	49.28b	58.42a	46.30b	46.93b	48.65b	50.90b

As shown in Table 5 , CP ruminal degradability differed among concentrates at various time points. Similar to DM and OM degradability, oat exhibited significantly higher CP degradability than the other nine concentrates at all time points ($P<0.05$) (except at 24, 36, and 48 h compared with wheat). At 24 h, oat CP degradability reached 72.64%, with wheat second at 63.25%. At 48 h, oat degradability reached 84.19%, while sorghum was only 38.77%. CP degradability increased slowly from 6–24 h and more rapidly from 24–48 h for all concentrates. Oat had significantly higher CP effective degradability than other concentrates ($P<0.05$). Among cereal grains, oat had the highest CP effective degradability, while among meals, peanut meal had the highest.

Table 5 CP ruminal degradability and degradation parameters of ten kinds of concentrates

Items	Sorghum	Barley	Wheat	Rapeseed meal	Peanut meal	Cottonseed meal	Soybean meal	cDDGS	P-value
Ruminal degradability of CP									
6 h	16.64d	24.25bcd	22.73cd	30.30b	44.30a	27.42bc	24.33bcd	29.19b	16.87d
12 h	20.10d	27.54cd	31.66cd	49.83b	63.53a	35.55c	28.63cd	31.53cd	20.28d
24 h	24.82c	32.77bc	39.66b	63.25a	72.64a	41.34b	40.82b	42.52b	34.15bc
36 h	36.18cd	37.66cd	48.51bc	70.28a	80.64a	47.56bc	48.55bc	54.55b	41.45bcd
48 h	38.77d	47.25cd	59.36bc	74.27a	84.19a	58.01bc	59.51bc	62.18b	54.02bc

Items	Sorghum	Barley	Wheat	Rapeseed meal	Peanut meal	Cottonseed meal	Soybean meal	cDDGS	P-value
Ruminal degradation parameters of CP									
a (%)	20.75d	25.33cd	21.23d	22.63d	46.97a	31.21b	27.38bc	27.68bc	22.90cd
b (%)	57.42ab	50.18b	59.70ab	63.05a	46.19b	48.39b	67.43a	66.83a	65.14a
c (%/h)	0.04bc	0.03cd	0.03bc	0.04bc	0.02d	0.04bc	0.04b	0.04bc	0.05a
ED (%)	45.08e	43.71e	44.38e	49.32de	60.87a	52.04bcd	57.26ab	54.62bcd	56.02abc

Correlation Analysis of Ruminal Effective Degradability, in Vitro Small Intestinal Digestibility of RUDP, and Nutrient Contents As shown in Table 6 , meal-type feeds generally had higher RUDP content and in vitro small intestinal digestibility than cereal grains. RUDP content ranged from 14.90% to 26.22% in meal-type feeds and 5.00% to 6.89% in cereal grains. The in vitro small intestinal digestibility of RUDP for the ten concentrates ranged from 80.10% to 92.86%.

Table 6 RUDP content and in vitro small intestinal digestibility of RUDP of ten kinds of concentrates

Items	Sorghum	Barley	Wheat	Oat	Rapeseed meal	Peanut meal	Cottonseed meal	Soybean meal	cDDGS	P-value
RUDP content (%)	5.76de	5.00e	5.76de	6.89d	5.93de	19.42b	26.22a	20.42b	21.07b	14.90c

Items	Sorghum	Barley	Wheat	Oat	Rapeseed meal	Peanut meal	Cottonseed meal	Soybean meal	cDDGS	P-value
in vitro small intestinal digestibility of RUDP (%)	84.69d	86.23cd	84.23d	84.10d	80.10e	89.25b	92.86a	92.31a	89.26b	87.31bc

Correlations among ruminal effective degradability, in vitro small intestinal digestibility of RUDP, and nutrient contents are presented in Table 7 . Significant positive correlations were observed among DM, OM, and CP effective degradability ($P<0.01$). CP effective degradability was significantly positively correlated with CP content ($P<0.05$) and significantly negatively correlated with NDF content ($P<0.05$). In vitro small intestinal digestibility of RUDP was significantly positively correlated with DM and CP contents ($P<0.01$), significantly positively correlated with ADF content ($P<0.05$), and significantly negatively correlated with OM content ($P<0.01$).

Table 7 Correlation between ruminal degradability, in vitro small intestinal digestibility of RUDP, and nutrient contents of ten kinds of concentrates

Items	ED of DM	ED of OM	ED of CP	in vitro small intestinal digestibility of RUDP
ED of DM	1			
ED of OM	0.799**	1		
ED of CP	0.881**	0.802**	1	

Items	ED of DM	ED of OM	ED of CP	in vitro small intestinal digestibility of RUDP
in vitro small intestinal digestibility of RUDP	0.624*	-0.437*	0.807**	1
CP content	0.249	-0.163	0.641*	0.864**
NDF content	-0.788*	-0.437*	-0.788*	0.641*

- mean significant correlation ($P<0.05$), ** mean extremely significant correlation ($P<0.01$).

Regression equations relating nutrient contents, ruminal effective degradability, and in vitro small intestinal digestibility of RUDP are shown in Table 8 . Both CP effective degradability and in vitro small intestinal digestibility of RUDP were affected by CP and NDF contents. When OM, ADF, and DM contents were included, the R^2 for the RUDP digestibility regression equation reached 0.896. Using DM, OM, and CP effective degradability, the R^2 for the RUDP digestibility regression equation was 0.814.

Table 8 Regression equations relating CP degradability and in vitro small intestinal digestibility of RUDP of ten kinds of concentrates

Items	Regression equation	R^2	P-value
CP effective degradability (Y) with CP content (X)	Y=0.46+0.19X		

Items	Regression equation	R^2	P-value
CP effective degradability (Y) with CP content (X_1) and NDF content (X_2)	$Y=0.55+0.18X_1-0.58X_2$		
CP effective degradability (Y) with ED of DM (X_1) and ED of OM (X_2)	$Y=0.05+0.47X_1+0.69X_2$		
in vitro small intestinal digestibility of RUDP (Y) with CP content (X)	$Y=0.82+0.18X$		
in vitro small intestinal digestibility of RUDP (Y) with CP content (X_1) and NDF content (X_2)	$Y=0.77+0.18X_1+0.28X_2$		

Items	Regression equation	R^2	P-value
in vitro small intestinal digestibility of RUDP (Y) with CP content (X_1), NDF content (X_2), and OM content (X_3)	$Y=0.28+0.24X_1+0.36X_2+0.48X_3$		
in vitro small intestinal digestibility of RUDP (Y) with CP content (X_1), NDF content (X_2), OM content (X_3), ADF content (X_4), and DM content (X_5)	$Y=2.75+0.35X_1+0.42X_2+0.62X_3+0.36X_4-2.93X_5$	0.896	
in vitro small intestinal digestibility of RUDP (Y) with ED of DM (X_1), ED of CP (X_2), and ED of OM (X_3)	$Y=1.08+0.17X_1+0.91X_2-1.57X_3$	0.814	

Discussion

Ruminal Degradation Characteristics of Ten Concentrates Feed degradation in the rumen is essentially a series of processes resulting from rumen microbial physiological activity on feed nutrients. As feed residence time in the rumen increases, nutrient ruminal degradability increases, with significant differences among feeds. Smaller feed particle size leads to higher nutrient ruminal degradability [?]. Dietary concentrate-to-forage ratio affects microbial flora, thereby influencing ruminal degradation. Previous studies reported that a concentrate-to-forage ratio of 4:6 and adequate intake to meet maintenance requirements should be used when determining ruminal degradability, though diet selection should consider the test feed and production conditions [?, ?]. This study found that CP effective degradability of meal-type feeds followed the order: peanut meal > soybean meal > cottonseed meal > rapeseed meal > cDDGS. Rapeseed meal contains glucosinolates, erucic acid, and oxazolidinethione, while cottonseed meal contains free gossypol, which inhibit rumen microbial decomposition [?, ?], resulting in lower ruminal degradability compared with other meal-type feeds. Similar results were reported by Zhao Hongtao [?] and Diao Qiyu et al. [?]. For cereal grains, CP effective degradability followed the order: oat > wheat > sorghum > barley > corn, with DM effective degradability showing the same trend. The physical structure of feed entering the rumen greatly influences nutrient effective degradability. The highly structured epidermis of cereal grains forms an effective barrier that hinders microbial degradation of internal nutrients. This epidermis is primarily composed of highly structured cellulose and hemicellulose, and the waxy cuticle in corn further impedes microbial invasion. The nutrient storage components of cereal grains are starch granules surrounded by a protein matrix, and the degree of association between this matrix and starch granules significantly affects the rate of microbial access to starch. Corn has a very dense protein matrix coating, resulting in lower nutrient ruminal degradability, whereas oat’ s protein matrix is easily penetrated by bacteria, leading to high ruminal degradability at the same incubation time. The protein matrix of wheat, barley, and sorghum is intermediate between corn and oat in terms of bacterial penetrability, resulting in intermediate degradability. However, differences in cell wall thickness and chemical structure among feeds also contribute to varying degradability. Similar results were reported by Diao Qiyu [?] and Li Ruili et al. [?]. Previous studies have shown that feed physical and chemical characteristics, such as CP composition, non-protein nitrogen, true protein nitrogen content, and anti-nutritional factors, directly affect ruminal degradation [?, ?, ?]. This study found positive correlations between effective degradability of DM, OM, and CP and their respective rapidly degradable fractions, consistent with findings by Liu Haixia et al. [?] and González et al. [?].

in Vitro Small Intestinal Digestibility of RUDP in Ten Concentrates The improved three-step in vitro procedure yielded an average in vitro small intestinal digestibility of RUDP of 87.03% for the ten common concentrates for mutton sheep, which falls between the NRC (2001) recommended value (80%) [?] and the AFRC (1993) recommended value (90%) [?]. Individual concentrate digestibility ranged from 80.10% to 92.86%, within the 65%–95% range reported by INRA [?]. Meal-type feeds showed higher RUDP digestibility than cereal grains, consistent with Zhou Rong et al. [?]. Yue Qun et al. [?] reported that high-protein feeds have stronger digestive action in the small intestine than low-protein feeds. Hvelplund [?] used the three-step in vitro method to determine the digestibility of rumen residues from six feeds and found large differences in RUDP digestibility among feeds, demonstrating the necessity of determining RUDP digestibility for individual feeds. Yue Qun et al. [?] used both mobile nylon bag and three-step in vitro methods to determine RUDP digestibility in 15 common feeds for ruminants, finding a strong positive correlation between the two methods (R^2=0.8912). This study found RUDP digestibility values of 90.20% for meal-type feeds and 83.87% for cereal grains, while Zhou Rong et al. [?] reported values of 81.93% and 73.47%, respectively, using the mobile nylon bag method. The ruminant gastrointestinal tract exhibits some rejection of nylon bags, resulting in shorter retention times and relatively lower RUDP digestibility. Additionally, this method includes large intestinal digestion and is affected by factors such as digesta. Zhu Yajun et al. [?] reported RUDP digestibility values for corn, wheat, rapeseed meal, cottonseed meal, soybean meal, and peanut meal of 80.54%, 83.66%, 86.44%, 86.77%, 95.12%, and 93.04%, respectively, using the improved three-step in vitro method. Wang Yan et al. [?] reported values of 96.33%, 87.13%, 87.70%, 89.27%, and 89.57% for soybean meal, cottonseed meal, rapeseed meal, corn, and barley, respectively. The values obtained in this study (86.23%, 84.23%, 84.10%, 89.25%, 92.86%, 92.31%, and 89.26% for corn, barley, wheat, rapeseed meal, peanut meal, cottonseed meal, and soybean meal, respectively) are similar to these previous reports. Oat showed relatively high ruminal degradability but lower RUDP digestibility. For ruminants, high ruminal degradability represents inefficient utilization, as excessive ruminal degradation reduces the amount of protein available for absorption in the small intestine, affecting nutritional requirements. This study demonstrated that RUDP digestibility was generally higher than CP ruminal degradability, consistent with Zhu Yajun et al. [?]. Previous studies have reported that large amounts of protein not degraded in the rumen can be well digested in the small intestine, with varying degradation degrees among different feeds [?, ?]. This study found that meal-type feeds had higher RUDP content than cereal grains, with peanut meal having the highest RUDP content at 26.22%. Rapeseed meal, cottonseed meal, and soybean meal had RUDP contents of 19.42%, 20.42%, and 21.07%, respectively, similar to values reported by Zhao Tianzhang et al. [?], indicating that feed type, particularly protein content, greatly influences RUDP content.

Correlations Between Ruminal Effective Degradability and in Vitro Small Intestinal Digestibility of RUDP This study demonstrated that CP and NDF contents of concentrates can effectively predict CP ruminal degradability and RUDP digestibility, with R^2 increasing when OM, ADF, and DM contents were included. Ruminant protein digestion and utilization are divided into RDP and RUDP. With constant feed intake, higher dietary CP content provides more abundant nitrogen sources for rumen microbes, promoting microbial growth and increasing microbial crude protein (MCP) synthesis, thereby elevating CP ruminal degradability. The CP entering the small intestine consists primarily of MCP and RUDP. Higher dietary CP levels increase the amount of digestible CP available in the small intestine, thus increasing RUDP digestibility. Similar results were reported by Yuan Cuilin et al. [?], Woods et al. [?], and Wang Yan et al. [?]. The CSIRO (2007) recommended using feed CP and RUDP contents to predict RUDP digestibility [?], and since RUDP content correlates with feed CP content, CP content can be used to predict RUDP digestibility. Rumen microbial activity is primarily responsible for feed degradation and synthesis in the rumen; high NDF content inhibits microbial synthesis, reducing CP ruminal degradability. Small intestinal absorption and utilization depend mainly on enzymatic digestion, and NDF can promote digesta motility [?], so appropriate dietary NDF content can enhance RUDP digestibility. Yuan Cuilin et al. [?] reported a negative correlation between RUDP digestibility and NDF content in roughages, possibly because high NDF content in roughages inhibits small intestinal enzymes more than it promotes digesta motility. Therefore, when experimental conditions or external environments are limiting, feed nutrient contents can be used to rapidly predict CP ruminal degradability and RUDP digestibility.

This study also found a strong correlation between RUDP digestibility and effective degradability of DM, CP, and OM (R^2=0.814). Concentrates contain minimal ash, so OM ruminal degradability is similar to DM ruminal degradability. DM ruminal degradability determines dry matter intake (DMI); as DM degradability increases, DMI increases, thereby increasing CP ruminal degradability. Similar results were reported by Wang Shuiping et al. [?] and González et al. [?]. When DM or OM ruminal degradability increases, the amount of DM or OM entering the small intestine decreases, reducing RUDP digestibility. As CP ruminal degradability increases, MCP synthesis increases, and since MCP constitutes a large portion of protein absorbed and utilized in the small intestine, RUDP digestibility increases. Therefore, ruminal nutrient degradability can be used to predict RUDP digestibility. Few previous studies have combined analysis of concentrate nutrient degradability and RUDP digestibility, limiting in-depth comparative analysis.

Conclusion

1. Individual concentrates exhibited different ruminal degradation characteristics, with oat showing higher nutrient ruminal effective degradability than other concentrates.

2. The regression equation between concentrate nutrient contents and in vitro small intestinal digestibility of RUDP (Y) was: Y=2.75+0.35CP+0.42NDF+0.62OM+0.36ADF-2.93DM (R^2=0.896).

3. The regression equation between in vitro small intestinal digestibility of RUDP (Y) and effective degradability of DM (X_1), CP (X_2), and OM (X_3) was: Y=1.08+0.17X_1+0.91X_2-1.57X_3 (R^2=0.814).

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